PDFs and searches: observations from simplistic studies

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PDF4LHC
CERN, 16 May 2014
Collider Reach

Types of questions that are natural to ask about future searches:

How soon will LHC@13TeV beat 8TeV searches?

What can high-lumi LHC (3000fb$^{-1}$) do compared to original LHC plan (300fb$^{-1}$)?

What is the gain from a future 33/50/100/150 TeV collider?
The proper way of doing it:

Generate Monte Carlo events for signal and background, process them through a detector simulation, design and carry out an optimal analysis, work out discovery/exclusion reach.

This is very time consuming (months of work!), and not always easy to do optimally.

Can we find an alternative that’s easy, quick and adequately good? (and in the process maybe learn some general lessons?)
There are already many well-designed searches

How do we leverage that experience to guesstimate future reaches?
A *rough* way of doing it

Suppose ATLAS/CMS are currently sensitive to Z’ of 3 TeV (95% $CL_s$, 8 TeV, 19 fb$^{-1}$)

Work out how many signal events that corresponds to

Find out for what Z’ mass you would get the same number of signal events at 14 TeV with 300 fb$^{-1}$ (assume # of background events scales same way)
What we’re discussing is solution of the following equation for $M_{\text{high}}$

\[
\frac{N_{\text{signal-events}}(M_{\text{high}}^2, 14 \text{ TeV, Lumi})}{N_{\text{signal-events}}(M_{\text{low}}^2, 8 \text{ TeV, } 19\text{fb}^{-1})} = 1
\]

Many complications (e.g. coupling constants & other prefactors) mostly cancel in the ratio.

Dependence on $M$ and on $\sqrt{s}$ mostly comes about through parton distribution functions (PDFs) & simple dimensions.
Instead of cross section ratio, use **parton luminosity ratio**

Assume dominance of a single partonic scattering channel, \(ij\) (you have to know enough physics to figure out which is most appropriate).

Equation we solve to find \(M_{\text{high}}\) is then

\[
\frac{\mathcal{L}_{ij}(M_{\text{high}}^2, s_{\text{high}})}{\mathcal{L}_{ij}(M_{\text{low}}^2, s_{\text{low}})} \times \frac{lumi_{\text{high}}}{lumi_{\text{low}}} = \frac{M_{\text{high}}^2}{M_{\text{low}}^2}
\]

The tools we use for this are LHAPDF and HOPPET

most plots with MSTW2008 NNLO PDFs
Does it work?
Try a Z’ search. Take a baseline analysis:

ATLAS, 0.2 fb⁻¹ @ 7 TeV excludes M < 1450 GeV
Try a Z’ search. Take a baseline analysis:

ATLAS, 0.2 fb\(^{-1}\) @ 7 TeV excludes M < 1450 GeV

“Predict” exclusions at other lumis & energies (assume q\bar{q})
Try a Z’ search. Take a baseline analysis:

**ATLAS,**
0.2 fb⁻¹ @ 7 TeV
excludes M < 1450 GeV

“Predict” exclusions at other lumis & energies (assume \( q\bar{q} \))

Compare to actual exclusions
Try a $Z'$ search. Take a baseline analysis:

**ATLAS**, 0.2 fb$^{-1}$ @ 7 TeV excludes $M < 1450$ GeV

"Predict" exclusions at other lumis & energies (assume $q\bar{q}$)

Compare to actual exclusions

Maybe it only works so well because it’s a simple search? (Signal & Bkgd are both $q\bar{q}$ driven)
Post/pre-dictions for excited quark exclusion reach

Post/pre-dictions for squark exclusion reach

Post/pre-dictions for stop exclusion reach

Post/pre-dictions for KK gluon exclusion reach

Post/pre-dictions for sequential Z' exclusion reach

**Plots for different reach predictions**

- **Gluino**
  - 7 TeV
  - 8 TeV
  - 13 TeV
  - 14 TeV

- **Squark**
  - 7 TeV
  - 8 TeV
  - 13 TeV
  - 14 TeV

- **Stop**
  - 7 TeV
  - 8 TeV
  - 13 TeV
  - 14 TeV

- **KK Gluon**
  - 7 TeV
  - 8 TeV
  - 13 TeV
  - 14 TeV

- **Sequential Z'**
  - 7 TeV
  - 8 TeV
  - 13 TeV
  - 14 TeV

**Integrated Luminosity**

- **fb^{-1}**

**Energy Levels**

- **7 TeV**
- **8 TeV**
- **13 TeV**
- **14 TeV**

**References**

- ATLAS
- CMS
- CDF

**Extrapolations**

- Post/pre-dictions

**Graphs**

- Integrated reach for different particles at various energies.
Why does (should) it work?

Parton luminosities fall off very fast with increasing $M_X$

Even when you make a mistake (e.g. wrong partonic mix)
the impact on estimated $M_X$ reach is modest

$x2$ in lumi $\sim 10\%$ in $M_X$
From your iPhone (or a generic browser)
cern.ch/collider-reach
Rule of Thumb #2
(apparently not widely known previously)

Increase luminosity by factor 10
→ reach increases by constant
\[ \Delta m \approx 0.07 \sqrt{s} \]
i.e. for \( \sqrt{s}=14 \text{ TeV} \), reach goes by up
\(~1 \text{ TeV} \)

No deep reason — a somewhat random characteristic of large-x PDFs.
Only holds for \( 0.15 \lesssim M/\sqrt{s} \lesssim 0.6 \)

3000 \( \text{ fb}^{-1} \)
v. 300 \( \text{ fb}^{-1} \)
Differences between PDFs?
PDF uncertainties?

mostly small

But let’s examine one exception
Impact of PDF uncertainties

Caveats
1) Implicit assumption of narrow $Z'$ is debatable at high $M_{Z'}/\sqrt{s}$
2) PDF uncertainties don’t play identically here and in actual search
NNPDF comes with much larger uncertainties than CTEQ or MSTW
Observation #1

For $x > 0.4$, NNPDF uncertainties grow much larger than CTEQ & MSTW’s.

This is perhaps not unreasonable: NNPDF more accurately reflects absence of anti-quark constraints at large $x$. 

NNLO $q\bar{q}$ luminosities (LHC 14 TeV)
Observation #2

NNPDF replicas start to go negative for $x>0.4$

Negative PDFs at small $x$ have long been accepted if $F_L>0$

To know how acceptable at large $x$, must study NNLO DY x-sect (beyond scope of our study so far)

Anyway being resolved in NNPDF3?
qqbar/qq lumi increases for $x > 0.5$ in NNPDF ($x > 0.7$ in MSTW)

Even if not constrained by data, this runs counter to our physical expectations (counting rules, etc.)

Maybe sets in at too high $x$ to be a practical issue?
Is there a roadmap for PDFs at LHC?
Emerging realisation that the $Z$ $p_t$ spectrum is a potentially very precise handle on PDFs\[\text{[quark \times glue \times } \alpha_s]\]

Today, will mainly be a vital confirmation(?) of existing knowledge.

$\bar{t}t$ is also a powerful handle, cf. 1303.7215

**Studies with Juan Rojo and Andi Weiler for ECFA HL-LHC workshop in October 2013**
e.g. of HL-LHC precision SM measurement: Z $p_t$ spectrum

For $p_t \sim 1$ TeV, HL-LHC could bring **5x gain in precision**!  
[but only if theory prediction is good enough — today only NLO]
What other processes will bring high precision?

This can motivate measurements and form part of HL-LHC programme (might there even be benefits from additional low-energy running?)

A roadmap now can also motivate future precise theoretical calculations
Summary

Differences between large-x antiquark PDF uncertainties in various PDF sets are not surprising in their own right.

What amount of physical insight should be incorporated into fits? Should stiffness of fitting functions be an explicit parameter in fits? (E.g. XYZ stiff fit, XYZ not so stiff fit).

**Roadmap** for PDF fits? What’s the interplay with future collider plans? What theory progress is needed on what timescale?
BACKUP SLIDES
Why does it work?
Post/predictions for gluino exclusion reach

reach for $2m_{\tilde{g}}$ [TeV] vs. integrated lumi [fb$^{-1}$]

- Extrapolations
- Reference (CMS)
- CMS

Signal gg; bkgd: gg

Signal gg; bkgd: qg

Scattering channel matters, but not too much
From your iPhone (or a generic browser)
cern.ch/collider-reach
From your Android Phone
(or a generic browser)
cern.ch/collider-reach
Collider 1: CoM energy $8$ TeV, integrated luminosity $20$ fb$^{-1}$
Collider 2: CoM energy $14$ TeV, integrated luminosity $300$ fb$^{-1}$

PDF: MSTW2008nnlo68cl

Mass [TeV] at collider #2

Mass [TeV] at collider #1

http://cern.ch/collider-reach by G.P. Salam and A. Weiler
Mass [TeV] at collider #1

Mass [TeV] at collider #2

Spread of partonic channels (assume same channel for S & B)
The Collider Reach tool gives you a quick (and dirty) estimate of the relation between the mass reaches of different proton-proton collider setups.

Collider 1: CoM energy 14 TeV, integrated luminosity 300 fb⁻¹
Collider 2: CoM energy 33 TeV, integrated luminosity 3000 fb⁻¹

PDF: CT10nlo

**Plots**

- Linear plot
- Log-log plot

**Download:** collider.pdf, colliderloglog.pdf, plot generation log file

The PDF choice was CT10nlo.LHgrid

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$14 \text{ TeV} 300 \text{ fb}^{-1} \rightarrow 100 \text{ TeV} 3 \text{ ab}^{-1}$
$14 \text{ TeV}_{300 \text{ fb}^{-1}} \rightarrow 100 \text{ TeV}_{3 \text{ ab}^{-1}}$

Collider Reach project by G. P. Salam and A. Weiler

The PDF choice was CT10nlo.LHgrid

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When you’ve lost your XPhone
Rule of Thumb #1
(well known among practitioners)

Increase collider energy by factor $X$ & increase luminosity by a factor $X^2$

→ reach goes up by a factor $X$

[Because you keep same Bjorken-x & luminosity increase compensates for $1/\text{mass}^2$ scaling of cross sections]

PDF scaling variations are small effect
Rule of Thumb #2  
(apparently not widely known previously)

Increase luminosity by factor 10  
→ reach increases by constant  
\[ \Delta m \approx 0.07 \sqrt{s} \]

i.e. for \( \sqrt{s} = 14 \) TeV, reach goes by up 1 TeV

No deep reason — a somewhat random characteristic of large-x PDFs.  
Only holds for \( 0.15 \lesssim M/\sqrt{s} \lesssim 0.6 \)
Consequence of rule #2
(may be a bit fragile & only for $S \approx B$)

Exclusion is $2-\sigma$
Discovery is $5-\sigma$
Need $(5/2)^2 = 6.25$ increase in lumi to go from one to the other.

Using rule #2:
discovery reach is about $0.05\sqrt{s}$
below exclusion reach
~ 0.8 TeV at 14 TeV
Future colliders

• We’re ignoring all subtleties, just going for a baseline check

• If our estimate differs a lot from sophisticated simulations, something interesting has happened:
  • brick-wall (new irreducible backgrounds, granularity of assumed detectors, …)
  • overly conservative or non-optimal estimates
Future colliders comparison

The ILC new physics program has been studied in great detail, and has excellent capabilities to discover and measure the properties of new physics, including dark matter, with almost no loopholes. A necessary requirement is that the new physics must be accessible. Essentially this means particles at sufficiently low mass missed by LHC due to blind spots, or heavy physics indirectly accessible through precision measurement. Discovery of physics beyond the standard model at LHC that is accessible at ILC would make the case even more compelling.

A 100 TeV pp collider has unprecedented and robust reach for new physics that is evident even with the preliminary level of studies performed so far. It can probe an additional two orders of magnitude in fine-tuning in supersymmetry compared to LHC14, and can discover WIMP dark matter up to the TeV mass scale. Any discovery at the LHC would be accessible at this machine and could be better studied there, making the case for these options even more compelling.

High energy e+ e− colliders such as CLIC and muon colliders offer a long-term program that can extend precision and reach of a wide range of physics.

A summary of the energy reach for a range of physics beyond the SM at various proposed facilities is shown in Fig. 1-1. This is a highly simplified plot. In particular, although the mass reach of hadron colliders is generally very impressive, hadron colliders searches often have blind spots, for example due to compressed spectra or suppressed couplings. Searches at e+ e− colliders are much more model independent, but generally have more limited mass reach. Many examples of this complementarity are discussed in the body of this report.

Energy Frontier Snowmass study (1311.0299)
Colorons

Collider Reach(β)™ estimates

14 TeV
300 1/fb

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<td>ee, 0.5 TeV</td>
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New Particles Working Group Report

• The ILC new physics program has been studied in great detail, and has excellent capabilities to discover and measure the properties of new physics, including dark matter, with almost no loopholes. A necessary requirement is that the new physics must be accessible. Essentially this means particles at sufficiently low mass missed by LHC due to blind spots, or heavy physics indirectly accessible through precision measurement. Discovery of physics beyond the standard model at LHC that is accessible at ILC would make the case even more compelling.

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Figure 1-1. 95% confidence level upper limits for masses of new particles beyond the standard model expected from pp and e+e- colliders at different energies. Although upper mass reach is generally higher at pp colliders, these searches often have low-mass loopholes, while e+e- collider searches are remarkably free of such loopholes.
Colorons

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![Graph showing the mass reach for different energies and collider types](image-url)
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100 TeV, 3000/fb
33 TeV, 3000/fb
14 TeV, 3000/fb
14 TeV, 300/fb
8 TeV, 20/fb
3 TeV, 1000/fb
1 TeV, 1000/fb
0.5 TeV, 500/fb

T Quarks

mass (GeV)

Collider Reach(β)™ estimates

T quarks

8 TeV

pp, 100 TeV, 3000/fb
pp, 33 TeV, 3000/fb
pp, 14 TeV, 3000/fb
pp, 14 TeV, 300/fb
pp, 8 TeV, 20/fb
ee, 3 TeV, 1000/fb
ee, 1 TeV, 1000/fb
ee, 0.5 TeV, 500/fb

A summary of the energy reach for a range of physics beyond the SM at various proposed facilities is shown.

Many examples of this complementarity are discussed in the body of this report.

High energy TeV mass scale. Any discovery at the LHC would be accessible at this machine and could be better

Precision measurement. Discovery of physics beyond the standard model at LHC that is accessible at

Low-mass loopholes, while collider searches often have low-mass loopholes, while

Discussion of such loopholes.

Figure 1-1. This is a highly simplified plot. In particular, although the mass reach of hadron colliders is

electron colliders at different energies. Although upper mass reach is generally higher at

collider searches are remarkably free

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discover and measure the properties of new physics, including dark matter, with almost no loopholes.
Figure 1-1. T Quarks

A summary of the energy reach for a range of physics beyond the SM at various proposed facilities is shown. The ILC new physics program has been studied in great detail, and has excellent capabilities to discover and measure the properties of new physics, including dark matter, with almost no loopholes. The LHC has unprecedented and robust reach for new physics that is evident even with its limited mass reach. Any discovery at the LHC would be accessible at this machine and could be better in fine-tuning in supersymmetry compared to LHC14, and can discover WIMP dark matter up to the preliminary level of studies performed so far. It can probe an additional two orders of magnitude in mass sensitivities. The LHC has great precision measurement. Discovery of physics beyond the standard model at LHC that is accessible at this machine could be even more compelling.

High energy colliders such as CLIC and muon colliders offer energy scales that are energetically lower than LHC, but can reach a significantly larger mass range. These colliders have very high luminosities, with an expected luminosity of 3000 fb⁻¹ for Tevatron 14 in a full year of running. This can give a very comprehensive search for new physics. The Tevatron is the best collider to find T quarks with low mass due to its energy range, while the LHC is better suited for searching for T quarks with high mass. Hadron collider searches often have blind spots, for example due to compressed spectra or suppressed couplings. Searches at the ILC have very high luminosities and sensitivity at a TeV mass scale. Any discovery at the LHC would make the case even more compelling.

The LHC14 has unprecedented and robust reach for new physics that is evident even with its limited mass reach. Any discovery at the LHC would be accessible at this machine and could be better in fine-tuning in supersymmetry compared to LHC14, and can discover WIMP dark matter up to the preliminary level of studies performed so far. It can probe an additional two orders of magnitude in mass sensitivities. The LHC has great precision measurement. Discovery of physics beyond the standard model at LHC that is accessible at this machine could be even more compelling.
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The ILC new physics program has been studied in great detail, and has excellent capabilities to discover and measure the properties of new physics, including dark matter, with almost no loopholes. A summary of the energy reach for a range of physics beyond the SM at various proposed facilities is shown. ILC would make the case even more compelling.
T Quarks

Issue seems to be detector granularity

Collider Reach(β)™ estimates

pp, 100 TeV, 3000/fb
pp, 33 TeV, 3000/fb
pp, 14 TeV, 3000/fb
pp, 14 TeV, 300/fb
pp, 8 TeV, 20/fb
ee, 3 TeV, 1000/fb
ee, 1 TeV, 1000/fb
ee, 0.5 TeV, 500/fb

Figure 1-1. This is a highly simplified plot. In particular, although the mass reach of hadron colliders is limited by detector granularity, searches at the LHC have access to a mass range that is unimaginable at other facilities. For example, a 100 TeV collider would make the case even more compelling.

A necessary requirement is that the new physics must be accessible. Essentially this means particles at such energies. Although upper mass reach is generally higher at high-energy e+e− colliders such as CLIC and muon colliders, these searches often have low-mass loopholes, while hadron collider searches are remarkably free of such loopholes.

The ILC new physics program has been studied in great detail, and has excellent capabilities to discover and measure the properties of new physics, including dark matter, with almost no loopholes. Precision measurement at the LHC has access to a mass range that is unimaginable at other facilities. For example, a 100 TeV collider would make the case even more compelling.

Any discovery at the LHC would be accessible at this machine and could be better studied there, making the case for these options even more compelling.

14 TeV precision and reach of a wide range of physics.

95% confidence level upper limits for masses of new particles beyond the standard model from the preliminary level of studies performed so far. It can probe an additional two orders of magnitude more than the LHC.

Isssue seems to be detector granularity.

T Quarks

A 100 TeV ILC would make the case even more compelling.

pp, 14 TeV, 3000/fb
pp, 100 TeV, 3000/fb
pp, 14 TeV, 300/fb
pp, 8 TeV, 20/fb
ee, 3 TeV, 1000/fb
ee, 1 TeV, 1000/fb
ee, 0.5 TeV, 500/fb

14 TeV
300 1/fb
14 TeV
3000 1/fb
33 TeV
3000 1/fb

mass (GeV)

0 20 1/fb
2000
3000
4000

T quarks

8 TeV
Gluinos

Collider Reach(β) estimates

- pp, 100 TeV, 3000/fb
- pp, 33 TeV, 3000/fb
- pp, 14 TeV, 3000/fb
- pp, 14 TeV, 300/fb
- pp, 8 TeV, 20/fb
- ee, 3 TeV, 1000/fb
- ee, 1 TeV, 1000/fb
- ee, 0.5 TeV, 500/fb
A necessary requirement is that the new physics must be accessible. Essentially this means particles at sufficiently low mass missed by LHC due to blind spots, or heavy physics indirectly accessible through hadron colliders searches often have blind spots, for example due to compressed fine-tuning in supersymmetry compared to LHC14, and can discover WIMP dark matter up to the 4 TeV mass scale. Any discovery at the LHC would be accessible at this machine and could be better studied there, making the case for these options even more compelling.

The ILC new physics program has been studied in great detail, and has excellent capabilities to discover and measure the properties of new physics, including dark matter, with almost no loopholes. A 100 TeV ILC would make the case even more compelling.

Discoveries at different energies. Although upper mass reach is generally higher at lepton colliders such as CLIC and muon colliders or a long-term program that can extend collider reach(β)™ estimates by, e.g., 20 1/fb for pp, 8 TeV, 20/fb, and 300 1/fb for pp, 14 TeV, 300/fb, pp, 14 TeV, 3000/fb, pp, 100 TeV, 3000/fb, pp, 33 TeV, 3000/fb, ee, 0.5 TeV, 500/fb, ee, 1 TeV, 1000/fb, ee, 3 TeV, 1000/fb, pp, 8 TeV, 20/fb, pp, 14 TeV, 300/fb, pp, 14 TeV, 3000/fb, pp, 100 TeV, 3000/fb, pp, 33 TeV, 3000/fb, pp, 14 TeV, 300/fb, pp, 8 TeV, 20/fb, ee, 3 TeV, 1000/fb, ee, 1 TeV, 1000/fb, ee, 0.5 TeV, 500/fb.
A summary of the energy reach for a range of physics beyond the SM at various proposed facilities is shown in Fig. 1-1. This is a highly simplified plot. In particular, although the mass reach of hadron colliders is generally very impressive, hadron colliders searches often have blind spots, for example due to compressed spectra or suppressed couplings. Searches at different energies. Although upper mass reach is generally higher at colliders such as CLIC and muon colliders compared to LHC, these searches often have low-mass loopholes, while electron colliders are much more model independent, but generally have more limited mass reach. Many examples of this complementarity are discussed in the body of this report.

A necessary requirement is that the new physics must be accessible. Essentially this means particles at a TeV mass scale. Any discovery at the LHC would be accessible at this machine and could be better in fine-tuning in supersymmetry compared to LHC. The ILC new physics program has been studied in great detail, and has excellent capabilities to discover and measure the properties of new physics, including dark matter, with almost no loopholes. The ILC would make the case even more compelling. Precision measurement. Discovery of physics beyond the standard model at LHC that is accessible at the preliminary level of studies performed so far. It can probe an additional two orders of magnitude that cannot be discovered at LHC due to their insufficient level of fine-tuning.

Gluinos:

**Collider Reach**

- **pp, 8 TeV**: 20 fb, 1 fb
- **pp, 100 TeV**: 3000 fb
- **pp, 33 TeV**: 3000 fb
- **pp, 14 TeV**: 3000 fb
- **pp, 14 TeV**: 300 fb
- **pp, 8 TeV**: 20 fb
- **ee, 3 TeV**: 1000 fb
- **ee, 1 TeV**: 1000 fb
- **ee, 0.5 TeV**: 500 fb

Collider Reach(β)™ estimates:

- **14 TeV**: 300 fb, 1 fb
- **14 TeV**: 3000 fb
Gluinos

14 TeV
300 1/fb

14 TeV
3000 1/fb

33 TeV
3000 1/fb

Collider Reach(β)™ estimates

- pp, 100 TeV, 3000/fb
- pp, 33 TeV, 3000/fb
- pp, 14 TeV, 3000/fb
- pp, 14 TeV, 300/fb
- pp, 8 TeV, 20/fb
- ee, 3 TeV, 1000/fb
- ee, 1 TeV, 1000/fb
- ee, 0.5 TeV, 500/fb

5800 GeV
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A 100 TeV pp collider has unprecedented and robust reach for new physics that is evident even with precision measurement. Discovery of physics beyond the standard model at LHC that is accessible at LHC14, and can discover WIMP dark matter up to the scientifically low mass missed by LHC due to blind spots, or heavy physics indirectly accessible through different energies. Although upper mass reach is generally higher at pp collider such as CLIC and muon collider options, discovery and measure the properties of new physics, including dark matter, with almost no loopholes. A necessary requirement is that the new physics must be accessible. Essentially this means particles at a TeV mass scale. Any discovery at the LHC would be accessible at this machine and could be better in fine-tuning in supersymmetry compared to LHC. A 100 TeV pp collider would make the case even more compelling. A 100 TeV pp collider has unprecedented and robust reach for new physics that is evident even with precision measurement. Discovery of physics beyond the standard model at LHC that is accessible at LHC14, and can discover WIMP dark matter up to the scientifically low mass missed by LHC due to blind spots, or heavy physics indirectly accessible through different energies. Although upper mass reach is generally higher at pp collider such as CLIC and muon collider options, discovery and measure the properties of new physics, including dark matter, with almost no loopholes. A necessary requirement is that the new physics must be accessible. Essentially this means particles at a TeV mass scale. Any discovery at the LHC would be accessible at this machine and could be better in fine-tuning in supersymmetry compared to LHC. A 100 TeV pp collider would make the case even more compelling.
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High energy collider searches are remarkably free of such loopholes. Essentially this means particles at a 100 TeV mass scale. Any discovery at the LHC would be accessible at this machine and could be better constrained than those at the lower TeV scale. Still, the accessible physics is quite limited. An example is supersymmetry: LHC14 can reach only a few TeV. Even the upper mass scale of LHC14 may be hard to probe due to the low luminosity of the machine. ILC would make the case even more compelling. Discovery of physics beyond the standard model at LHC that is accessible at LHC14, and can discover WIMP dark matter up to the TeV mass scale. Any discovery at the LHC would be accessible at this machine and could be better constrained than those at the lower TeV scale. Still, the accessible physics is quite limited. An example is supersymmetry: LHC14 can reach only a few TeV. Even the upper mass scale of LHC14 may be hard to probe due to the low luminosity of the machine. ILC would make the case even more compelling.

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